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(54) **Pneumatic flexible-walled spring**

(57) A rolling diaphragm pneumatic spring comprises two hollow rigid bodies, 2, 13, coaxial with one another and one extending partially into the other. The bodies are connected to one another by a substantially cylindrical membrane 5 which is made of a pre-compressed elastomeric material and which is internally reinforced by wires extending parallel to one another according to the generatrices of the cylindrical shape.

The spring may comprise more than two such bodies connected to one another by two or more such membranes.

At least one of the rigid bodies 2, 13 has a variably shaped wall, over which the membrane rolls.

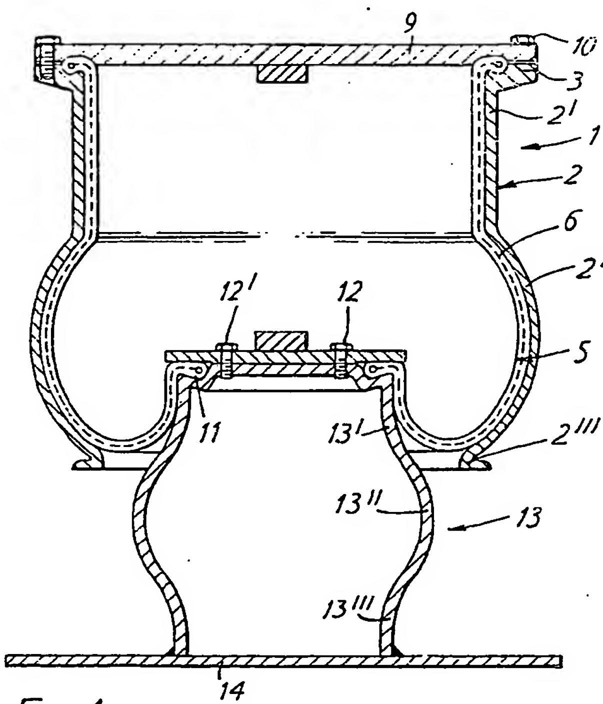

FIG.1

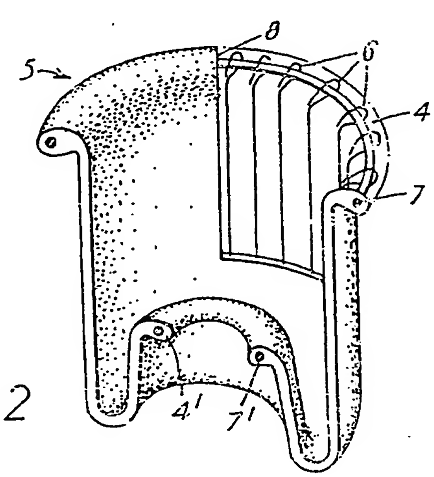

FIG.2

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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

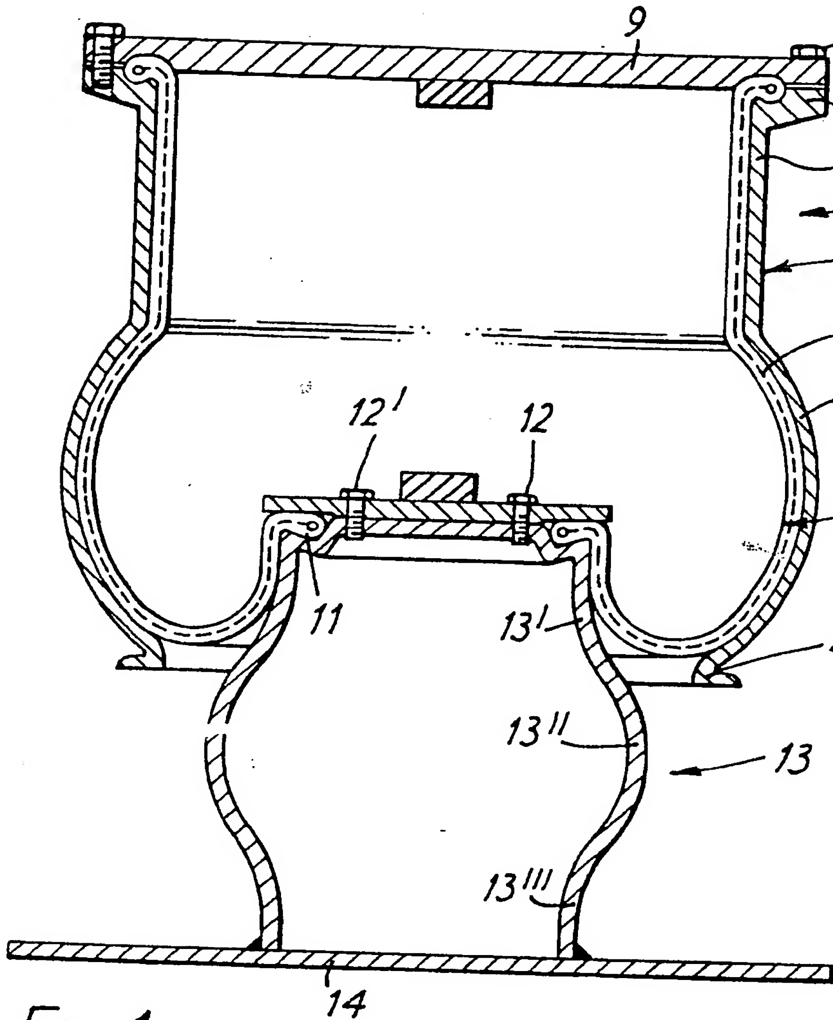

FIG. 1

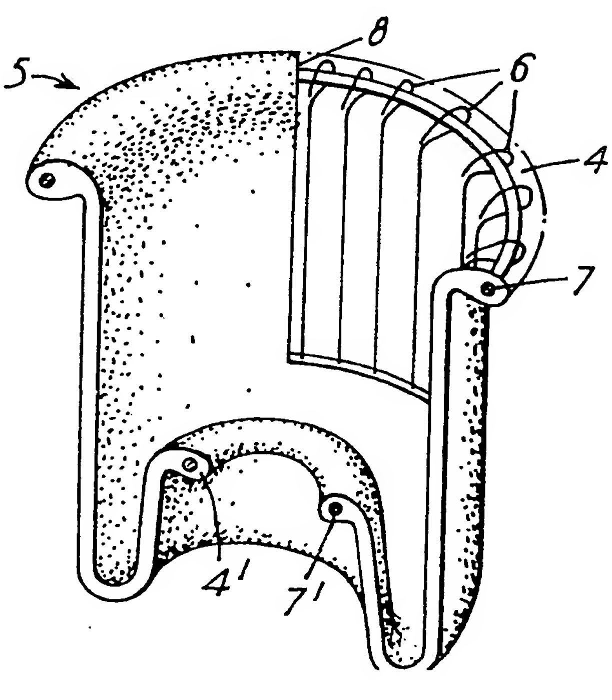

FIG. 2

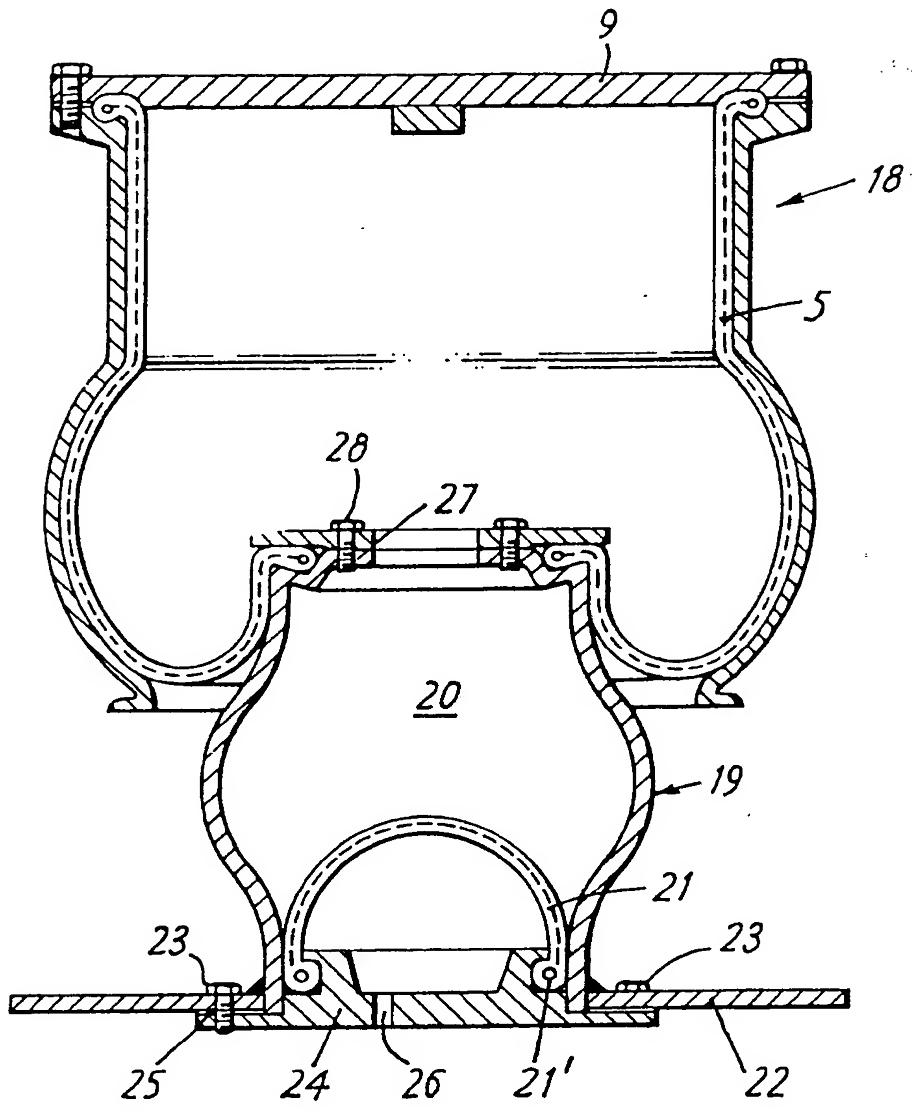

FIG.3

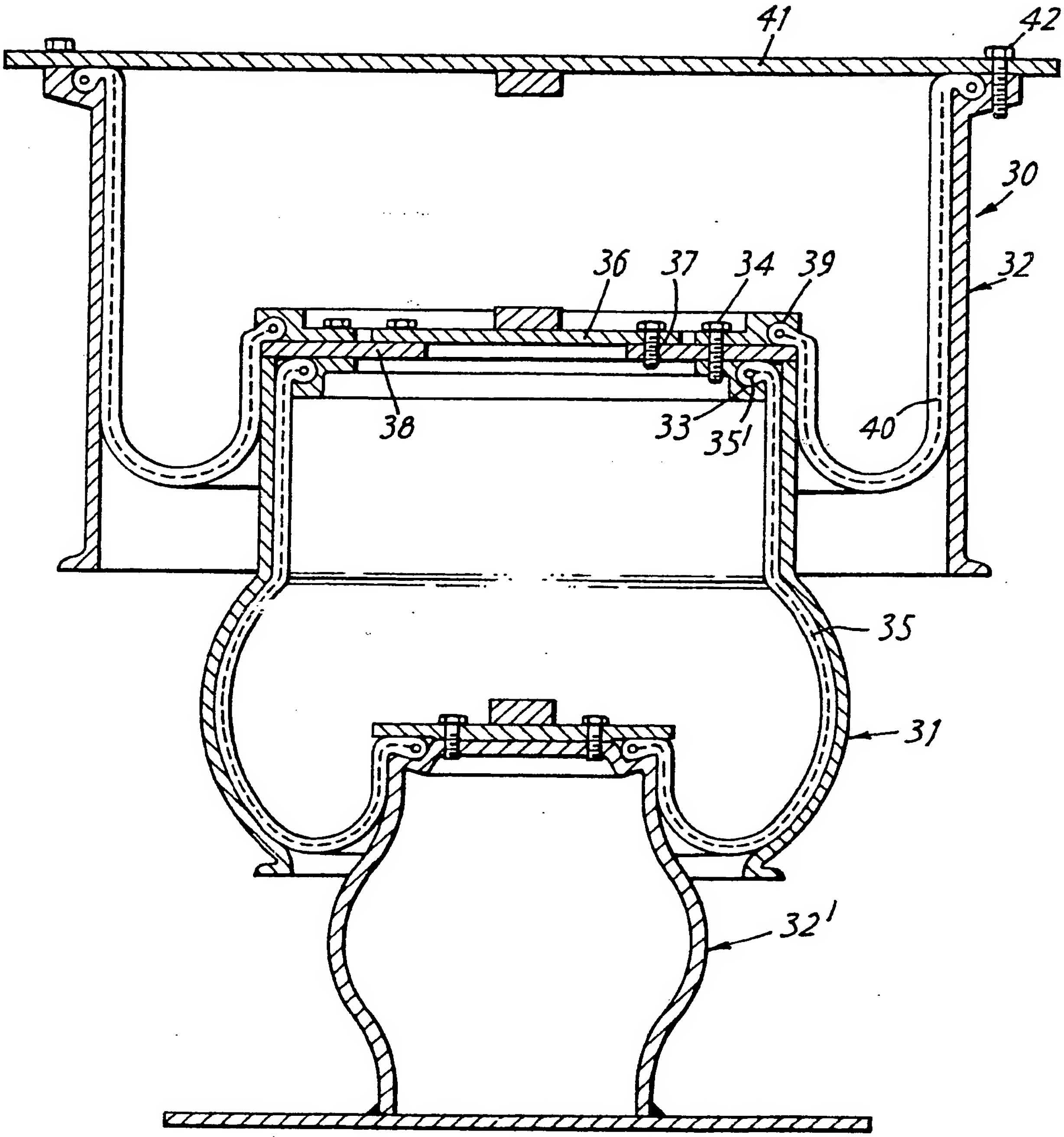

FIG.4

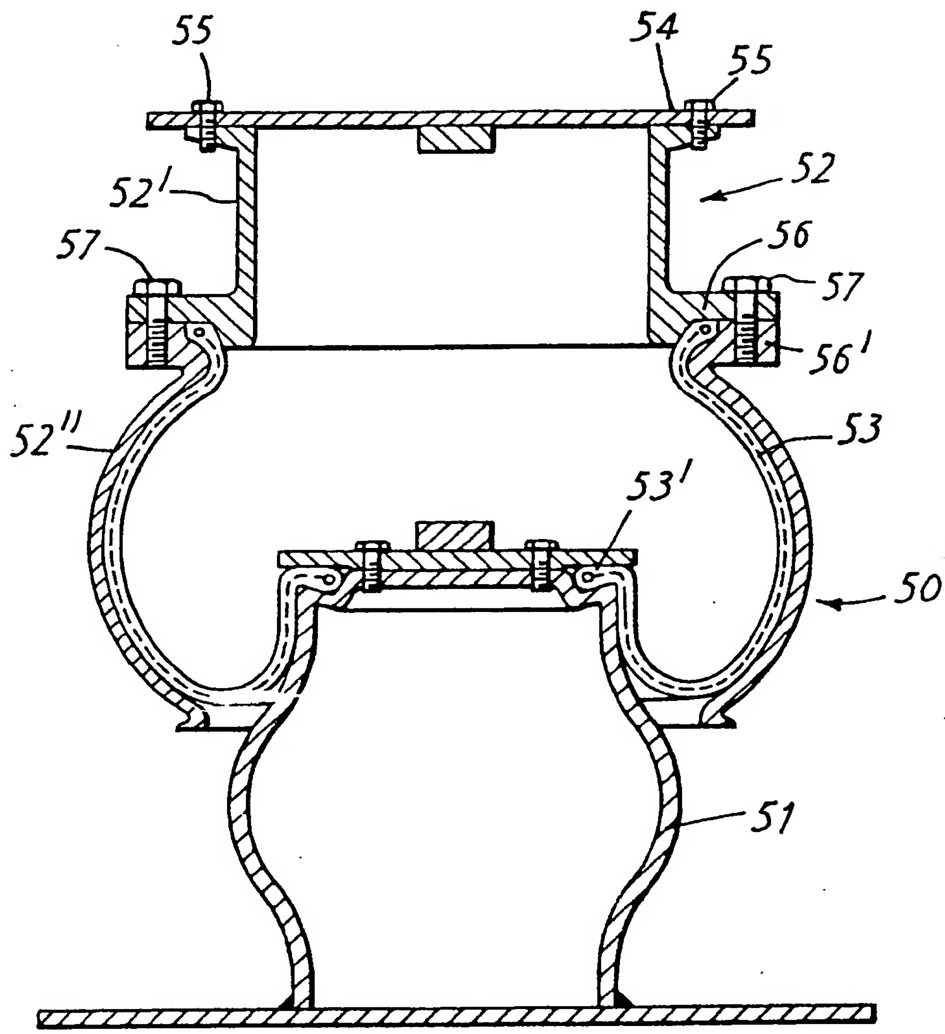

FIG.5

SPECIFICATION
Pneumatic spring

This invention relates to a pneumatic spring. A bell-shaped pneumatic spring essentially comprises a flexible casing into which there is introduced pressurized air for balancing the external load and bell-shaped pneumatic springs have a vast field of application. They serve, for example, as suspensions of motor-vehicles in which a particular standard or degree of riding-comfort is desired or in vehicles in which there is too high a ratio between the weights of the vehicle fully loaded and empty. Their use also extends to suspension systems for fixed plant which have to be insulated against vibrations originating from outside or else to suspensions which are used to isolate from vibrations the zones adjacent to a vibrating machine. Moreover, they are used to make "pneumatic" jacks as an alternative to the more costly "hydraulic" jacks, and so on and so forth.

The known bell-shaped pneumatic springs generally comprise a fabric-rubber membrane with thin flexible walls and serving as a container for the pressurized air which constitutes the 'carrier element' which provides the elastic reaction of the spring. The fabric of the membrane has to absorb or cope with the tensions which originate from the air-pressure inside the membrane and which balance the external load applied to the springs; it generally comprises two layers of wires and cords disposed in an oblique direction with respect to the longitudinal axis of the membrane, the cords in each layer being in a biased position with respect to those in the other layer or it comprises one or several layers of wires disposed according to the direction of the longitudinal axis of the spring. The rubber layer or layers which cover(s) or complete(s) the fabric has the purpose of rendering the membrane impermeable and resistant to attack by any chemical, atmospheric or other agents.

The membrane has a substantially cylindrical or toroidal form. In the first case, it can be wrapped inside or folded into a metallic band or a fabric-rubber or metal cylinder, the function of said band or cylinder being to contain or prevent transverse deformations of the spring during use. In the second case, the membrane generally presents a certain number of overlapped or superimposed loops between which there are interposed metallic reinforcing rings for controlling any transversal deformations. The membrane is closed off at its ends by special flanges or metallic plates which also serve as part of the means for fixing the spring to the structure (e.g. vehicle or plant) for which it is desired.

Under exercise conditions, the wires comprising part of the fabric of the membrane are subjected to stresses which are directly proportional to their radius of curvature. This signifies that, for a given pressure of exercise, the greater the radius of curvature of a wire, the greater in proportion will be the tension to which the wire is subjected. In a membrane built with crossed plies, the radii of curvature of the wires are always greater than the diameter of the membrane, and they are, as a consequence, relatively large. The stresses to which the wires are subjected are considerable in this case and they necessitate the maintenance of fluid pressure to within a maximum limit of 7—8 Kg/cm².

Another drawback of the membrane having crossed plies and overlapped fabric layers is that, under exercise conditions, there are always relative shiftings between one layer and the layer adjacent to it due to the variations of the angle of intersection between the two layers. This gives rise to tangential tensions or, more precisely, to shear stresses in the coverings of the wires and said shear stresses could produce small tears and small separations in the rubber. This situation becomes aggravated and, in a short time, it leads to a deterioration of the membrane itself, due to fatigue.

From this viewpoint, it is therefore preferable to adopt a membrane having its fabric threads directed substantially according to the longitudinal axis of the spring; it being even better if they are disposed in a single layer. In such a case, however, the membrane presents positions, axially of the spring, in which the radius of curvature of the fabric threads are very large, with the result that these threads are subjected to very high stresses. This problem was solved by reinforcing the membrane with a metallic circumferential band, or else with a rubber-fabric or metal cylinder fitted-on over its external lateral surface; in this way, the stresses to which the membrane strands are subjected (in the portions having a wide radius of curvature) become contrabalanced by the walls of the reinforcing element. A spring of this type substantially comprises two co-axial cylinders, having different diameters, one of which is hollow. These two cylinders can slide axially one with respect to the other, and the hollow cylinder, with a larger diameter, partially or completely receives the other. Inside the hollow cylinder, there is housed a membrane of the type described (i.e. rubber-fabric—with the fabric having longitudinal threads) with one extremity thereof anchored to the hollow cylinder and with the other extremity thereof anchored to the other cylinder. The external surface of the membrane rests (for a part of its longitudinal development) against the internal surface of the wall of the hollow cylinder and against the external surface of the wall of the other cylinder; there is, however, the U-shaped bight portion which lies between or connects said two parts of the membrane and this bight portion in use of the spring is not supported by a wall or walls. The U-shaped bight portion having a small radius of curvature, is well able to resist the stresses that are originated by the air pressure in the membrane.

However, the known springs of the construction described in the preceding paragraph present the following drawbacks:

the U-shaped bight portion of the membrane is exposed to the light; that, as is known, causes a quickening in the ageing process of the elastomeric materials, especially when the latter are subjected to cyclic tractional stresses, as in the case in question;

with the two cylindrical elements, between which is interposed the membrane having the longitudinal fabric reinforcing threads, it is not possible to have any variation of the effective area during the "course" of the spring, by which is meant the passage from the maximum to the minimum axial distances between the two cylinders.

By "effective area" (Ae) is meant the area delimited by the circumference, having points wherein the tangent to the curvature of the deformable casing is perpendicular to the direction of the load acting upon the spring itself. The effective area has the following correlation with the exercise pressure of the spring and to the load applied thereto:—

$$p=\frac{P}{Ae}$$

where:

p=exercise pressure

P=applied load

Ae=effective area.

For a determined spring, by varying the value of the effective area, along the "course" thereof, it is possible to vary the thrust of the spring, and this circumstance translates into a variation of the curve relative to the thrust-course of the spring. Similarly, on varying the load, it is possible to maintain constant the rigidity of the spring or to cause it to vary according to a law of stability, through the means of an appropriate variation of the values of the effective areas.

From what has been stated above, it can be readily understood that the impossibility of the known springs to vary the values of the effective areas, depending upon the course of the spring, represents a considerable drawback.

The principal aim of the present invention is to provide a bell-shaped pneumatic pressurized gas spring which does not present any of the above-stated drawbacks, which, in particular, permits the use of pressures up to 15 Kg/cm^2, and which, at the same time, possesses optimum characteristics of durability and reliability although employing membrane, reinforcing wires which have a lower resistance than to those used at present. The spring described in the preceding sentence will present, compared with known springs, also other advantages that will be discussed during the following description.

Accordingly, the present invention consists in a bell-shaped pneumatic spring which is apt for containing pressurized air and which comprises at least two rigid hollow elements of a substantially tubular form, co-axial with one another and with the possibility of moving axially one with respect to the other, at least one element being open at at least one end thereof, and at least one element having variably shaped walls; at least one flexible membrane interposed between said rigid elements and comprising a plurality of wires or cords which are substantially inextensible, disposed substantially according to the longitudinal direction of the axis of the spring, and embedded in a layer of rubber; and means for connecting the membrane or membranes to the rigid elements.

Some embodiments of the present invention will now be described, as non-limiting examples, with reference to the accompanying drawings, in which:—

Figure 1 shows a longitudinal cross-section of a first embodiment of a bell-shaped pneumatic spring according the invention;

Figure 2 shows a perspective view of a membrane of which one half has been cut away and of which some of the rubber covering has been removed for better understanding of the component elements; and

Figures 3, 4 and 5 show longitudinal cross-sections of second, third and fourth embodiments of a bell-shaped pneumatic spring according to the present invention.

According to the more general idea of solution of a bell-shaped pneumatic spring according to the present invention this comprises at least two rigid elements of a generally tubular form which are coaxially arranged and which have the possibility of moving one with respect to the other along their common axis, at least one of said elements being open at at least one of its ends and at least one of said elements consists of a variably shaped wall.

These elements are positioned in a sequence according to the direction of the longitudinal axis of the spring with the result that one is at least partially within the other.

In fact, for any pair of consecutive elements, one of the two elements is open at only one end, or closed, whereas the other of said two elements is always open at least at one end and has transverse dimensions which are greater than those of the first in order to allow it to be received inside the first at least partially.

Between one element and the next, there is interposed and connected to them (at their extremities) a flexible membrane, comprising a plurality of wires (or cords) which are substantially inextensible and which are embedded in a layer of rubber and which are substantially disposed according to the direction of the longitudinal axis of the spring.

The membrane that acts as a connection between two rigid elements, is bent in a U-shape in the space comprised between the inner surface of that element which is of larger transverse dimensions and the outer surface of the other element. It is, moreover, as will be explained later,

pre-compressed for the purpose of having a greater resistance to stresses and to the effects of light.

Referring to Figures 1 and 2, there is shown a bell-shaped pneumatic spring 1 which comprises a rigid element 2 which is hollow and substantially tubular; in particular, said tubular element comprises a cylindrical portion 2′, a convex portion 2″ and a terminal portion 2‴, all of said portions being conjoined. A second rigid element 13 extends into the element 2 for a small distance and is also co-axial with said element 2. The element 13 has a substantially tubular form and comprises a first portion 13′ of cylindrical form, a second portion 13″ of a convex shape and a third portion 13‴ of cylindrical form.

In the space between the two elements 2 and 13 there is a membrane 5 comprising a series of flexible and substantially inextensible wires 6 each of which is disposed substantially longitudinally (i.e. parallel to the spring axis) and is embedded in rubber 8 which is generally based on neoprene. The membrane 5 has a diameter approximately equal to the maximum internal diameter of the element 2 and has an upper end 4 which includes a ring 7 of hard rubber or of metal. Said end 4 extends into a special seat 3 formed therefor in the flanged upper end of the element 2. A metallic plate 9, fixed to said flanged upper end by means of bolts 10, closes the upper end of the element 2 and locks the end 4 of the membrane 5 in the seat 3.

The outer surface of the membrane 5 is in contact with the inner surface of the element 2 and with the outer surface of the element 13 except for that part thereof which is bent into a U-shape which is clearly shown in Figures 1 and 2.

The second end 4′ of the membrane 5 includes a ring 7′ made of hard rubber or of metal, said ring 7′ having a smaller diameter than that of the main body of the membrane 5. Therefore, the end 4′ is forced to assume a diameter corresponding to that of the ring 7′.

The wires 6 are turned, at their respective ends, about the rings 7 and 7′, this condition being clearly shown in Figure 1 relative to the ring 7.

In this manner, the wires 6, which are initially parallel to each other, converge slightly in the longitudinal direction of the spring and in the direction that goes from ring 7 to ring 7′ or *vice versa*. Correspondingly, the rubber cladding of the wires 6 of the membrane 5, is as a result compressed, particularly in correspondence of that terminal portion which is in the vicinity of the end 4′. This fact (as we shall explain further on) represents an advantage.

The end 4′ is housed in a special seat 11 formed therefor on the upper end of the element 13, and it is locked in that seat by a circular metallic clamping plate which is fixed by means of screws 12′ to the element 13. The latter is welded at its other end to a metallic base 14.

In Figure 3, there is shown a second embodiment of a bell-shaped pneumatic spring 18 comprising a rigid element 19 which differs from the rigid element 13 of the spring 1 in that it is open at one end thereof in order to place its interior 20 in direct communication with the space delimited by the membrane 5 and by the metallic plate 9. In this embodiment, the lower end of the membrane 5 is fixed to the element 19 by means of a ring 27 and screws 28.

Another deformable membrane 21 made of rubber-fabric or of elastomeric material extends into the interior 20 of the element 19. The membrane 21, when in a stretched condition, has a form which is substantially hemispherical, and it has its periphery reinforced by a ring 21′ of hard rubber of metal, and it is anchored to a base plate 22 of the element 19 by means of a metallic plate 24 which is itself fixed to said plate 22 by means of screws 23. Between the plate 24 and the base 22, there is interposed a fluid-tight gasket 25 of known type and there is an opening 26 in the plate 24 for the passage of a pressurized liquid.

It is possible to introduce a pressurized liquid into the space delimited by the membrane 21 and by plate 24 and said liquid determines the degree of inflation of the membrane 21 which, in turn, reduces the volume of the compressed air contained in the spring 18 and, hence, enables the "compression ratio" (i.e. the value of the ratio between the volume of compressed air in the spring measured, respectively, under conditions of maximum and minimum elongation of the spring itself) to be varied. The possibility of varying the compression ratio:

$$\frac{V\ max.}{V\ min.}$$

(where V-max. indicates the volume of compressed air under conditions of maximum elongation of the spring, and V-min. indicates the volume of compressed air under conditions of minimum elongation of the spring) means that it is possible to influece the degree of rigidity of the spring. In this instance, there are further means available for varying the functioning of the spring as desired, in relation to the type of usage and to the variations in the load applied to it.

In Figure 4, there is shown a third embodiment of a pneumatic spring 30 which comprises three hollow, rigid elements 32′, 31 and 32 all of which are movable, one with respect to the other, each along its own axis. Each of the elements 31 and 32 is open at one end. The element 32 has a cylindrical form and partially receives the element 31 which has a form similar to that of the element 2 of the spring 1 of Figure 1. The element 31 partially receives, in turn, the element 32′ in a manner similar to that already described for the element 13 of Figure 1.

The upper end of the element 31 is partially closed by a circular annulus 38 which is solid with the rest of the element 31 and which is provided with a central circular opening for the purpose of

allowing a ring 33 to be set-up. This ring 33 is fixed by means of studs and screws 34 to the annulus 38 and it has the purpose of clamping the upper end of a membrane 35 (which is substantially the same as the membrane 5 of the spring 1), said upper end being reinforced by a ring 35′ of hard rubber or metal.

The upper end of the element 31 is closed by a metallic disc 36 fixed to the annulus 38 by screws 37 and, between the disc 36 and the element 31, there is interposed a fluid-tight seal of known type. At the upper outer edge of the element 31, there is fixed (by means of the same studs and screws 34 that connect the ring 33 to the annulus 38) a metallic ring 39 so shaped as to clamp the lower end of a membrane 40 which is of the type already described and whose upper end is connected (for example, in the way described with reference to Figure 1) to the upper end of the element 32, and it is bent in a U-shape in the space between the outer surface of the element 31 and the inner surface of the element 32.

The element 32 has a substantially cylindrical form and its upper end is closed by a plate 41 which is fixed to it by means of studs and screws 42, said plate 41 clamping said upper end of the membrane 40 against the element 32.

Figure 5 shows a fourth embodiment which comprises a pneumatic spring 50 having an element 51 which is the same as the rigid element 13 of the spring 1, and a second rigid element 52 having an overall form substantially the same as that of the rigid element 2 of said spring 1 but with the difference that the element 52 is formed by two separable parts 52′ and 52″. The two elements 51 and 52 are co-axial with the element 51 partially inside the element 52. Inside the rigid element 52, there is housed a membrane 53 which is shorter axially of the spring than the membrane 5 of the spring 1.

The lower end 53′ of the membrane 53 is anchored (in the same manner as that described for the membrane 5 of the spring 1) to the rigid element 52 whereas the upper end of the membrane 53 is anchored to the element 52 at the junction of the two portions 52′ and 52″ thereof. In order to facilitate this, the portion 52′ has a flange 56 and the portion 52″ has a flange 56′, the flanges being fixed to each other by screws 57 and clamping said upper end of the membrane between them. A metallic plate 54 closes the upper end of the element 52 and is fixed in position by means of screws 55.

With a bell-shaped pneumatic spring, according to the present invention as exemplified by any of the described embodiments the stated aims are duly achieved. In fact, it allows for varying, in any desired way, the effective areas of the spring—either through having a suitable shaping of the walls of at least one of the rigid borders of the spring; or else, by means of varying the compression ratio obtained by introducing an appropriate quantity of liquid into the space delimited by a membrane contained in one of the rigid bodies of the spring. The variation of the effective area determines the varying of the degree of rigidity of the spring—i.e. of its performance characteristics under exercise conditions.

As a result, it is possible (by acting upon the variations of the effective areas and upon the compression ratio) to obtain optimum functioning, within the limits of its mechanical resistance, under any load conditions whatsoever and under any types of stresses whatsoever.

The use of one or several "precompressed" membranes (depending upon the number of rigid elements forming part of the spring) determines a greater resistance of the rubber to the effects of light, especially in the zone where the membrane is more exposed, namely, in the zone corresponding to the open end of the rigid element in which it is housed. In said zone, under conditions of maximum exposure to light (spring completely elongated), the membrane presents the zone in which the rubber is in a condition of maximum compression of the rubber and, hence, has the maximum resistance to deterioration resulting from the known effects of light.

Moreover, because the "precompressed" membrane is more resistant to stresses, greater service-life and reliáblity thereof are obtained.

A further advantage of a pneumatic spring, according to the present invention consists in being able to make a membrane out of a fabric or longitudinal wires having small dimensions than those of the fabric or wires used in known springs of similar dimensions and course (rate). In fact, in a pneumatic spring according to the present idea of solution of the invention, it is possible to anchor one end of the membrane in an intermediate position between the ends of the element in which the membrane is housed and this enables the same results to be obtained by utilizing a membrane which does not quite completely cover the inner wall surface of the element which houses it, and by using (through the action of the content of pressurized air) one part of the actual wall of the element.

Claims

1. A bell-shaped pneumatic spring apt for containing pressurized air and comprising at least two rigid, hollow elements of a substantially tubular form, co-axial with one another and movable axially one with respect to the other; at least one of said elements being open at at least one end thereof and at least one of said elements having a variably shaped wall; at least one flexible membrane interposed between one and another of said rigid elements, said membrane comprising a plurality of wires or cords which are substantially inextensible and which are disposed substantially according to the longitudinal direction of the axis of the spring and which are embedded in rubber; and means for connecting the membrane or membranes to the rigid element(s).

2. A spring according to Claim 1, wherein the membrane is pre-compressed.

3. A spring according to claim 2, wherein the rigid elements are two in number and have their cavities respective interior in direct communication with each other.

4. A spring according to Claim 3, wherein, in the interior of one of the two rigid elements, there is housed a deformable element into which a pressurized liquid is introduced.

5. A spring according to any one of the preceding Claims, wherein one end of each membrane is anchored circumferentially to the rigid element in which it is housed, said anchorage being effected at the junction between the ends of the two portions which constitute the rigid element itself.

6. A spring according to Claim 5, wherein said junction is approximately equidistant from the other respective ends of said two portions.

7. A bell-shaped pneumatic spring constructed, arranged and adapted to operate substantially as hereinbefore described with reference to and as illustrated in Figures 1 and 2 or Figure 3 or Figure 4 or Figure 5 of the accompanying drawings.

8. Any features of novelty, taken singly or in combination, of the embodiments of the invention hereinbefore described with reference to the accompanying drawings.

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